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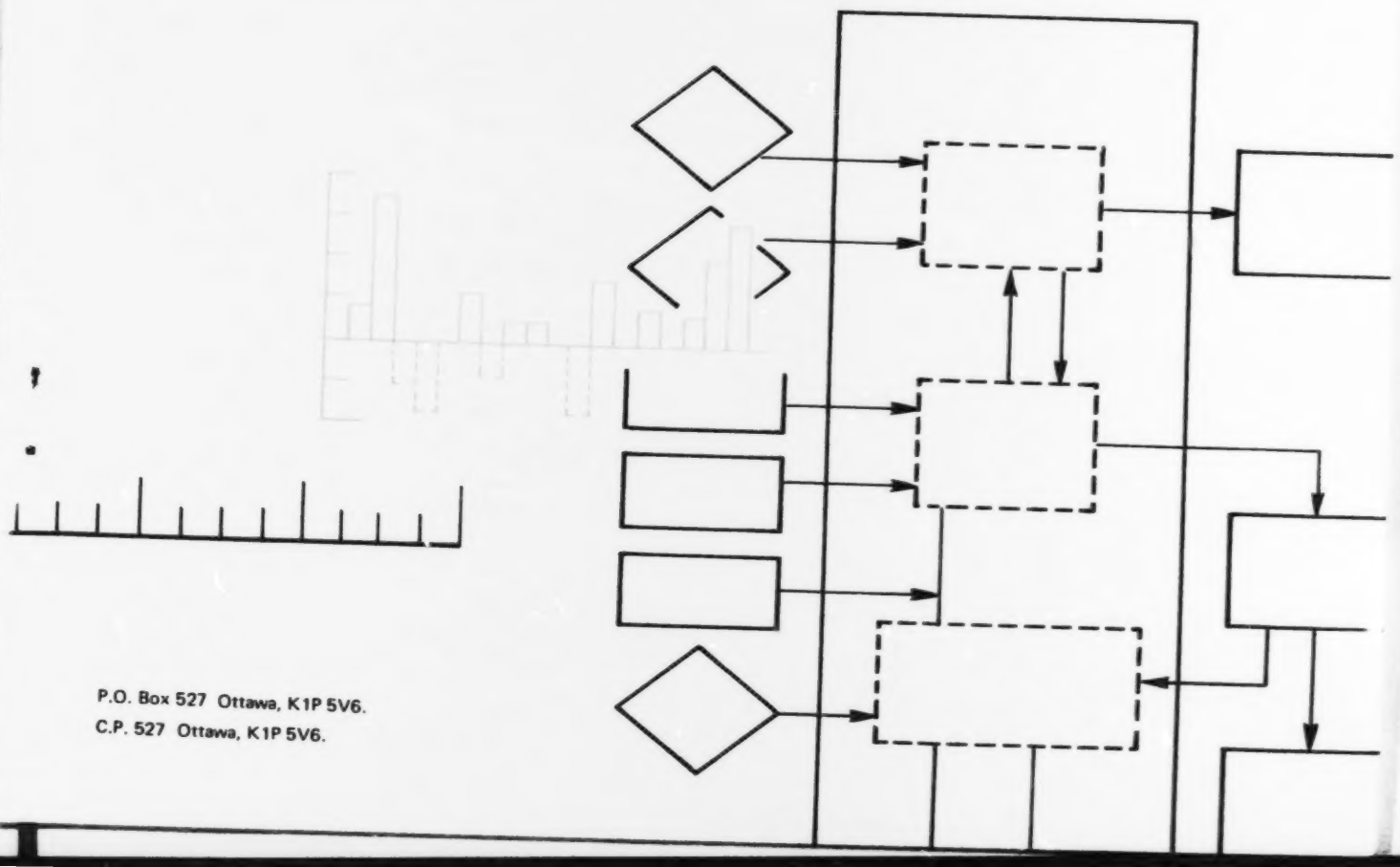

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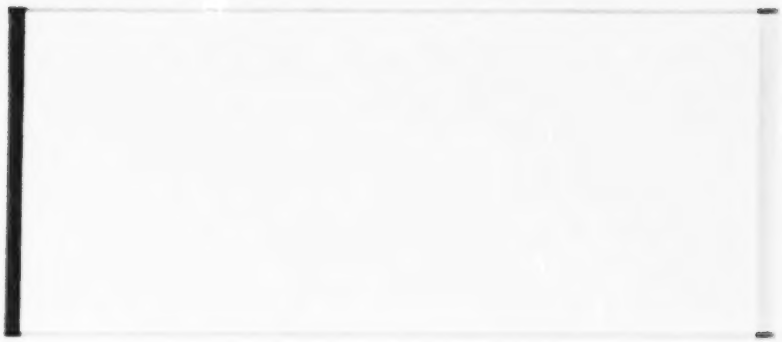

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DISCUSSION PAPER NO. 236

Productivity Growth, Economies of Scale, and Capacity Utilization in the Canadian Electric Power Industry: The Case of Ontario Hydro

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Abstract

This paper explores the sources of output and productivity growth at Ontario Hydro, one of the largest producers of electric power in North America. Particular attention is focused on the contribution of capacity utilization, scale economies, and technical change to growth in total factor productivity. Our empirical results suggest that the post-1973 decline in Ontario Hydro's productivity growth was mainly due to a marked decline in the growth of demand for electricity and a slowdown in technical progress as a result of increasing fuel prices.

RÉSUMÉ

Les auteurs du présent document étudient les sources de la croissance de la production et de la productivité à l'Hydro-Ontario, un des plus grands producteurs d'électricité en Amérique du Nord. Ils tentent en particulier de déterminer dans quelle mesure le degré d'utilisation de la capacité de production, les économies d'échelle et le progrès technologique contribuent à la croissance de la productivité de l'ensemble des facteurs. D'après les résultats empiriques obtenus, la plus faible croissance de la productivité à l'Hydro-Ontario depuis 1973 est principalement attribuable à la croissance sensiblement moins rapide de la demande d'électricité et au ralentissement du progrès technologique résultant de la hausse du prix des carburants.

1. INTRODUCTION

Perhaps the most disturbing feature of Canada's recent economic performance, and indeed that of all other major industrialized countries, concerns the dramatic decline in productivity growth that has taken place since the mid-1970s. Whereas during the period 1967-73 total factor productivity grew at an average annual rate of 2.2 per cent, for the period 1974-80 it ceased growing altogether. Not surprisingly, this slowdown has generated renewed interest in the measurement and explanation of productivity change and spawned a great deal of empirical research at both the national and industry level into the possible reasons for the slowdown.

However, it is at the firm level that the measurement and explanation of productivity growth is of greatest importance. If firms are to be managed efficiently, productivity assessment needs to be integrated into the process of managerial control and planning. Productivity models should serve to sharpen management's perception of the firm's operations and thereby assist the decision-making process. In this regard, analysis of past performance can provide valuable insights into the firm's ability to respond to changing operating conditions. Unfortunately, with the exception of two studies, one by Caves and Christensen (1980) of railroads, and the other by Denny, Fuss and Waverman (1981) of telecommunications, very little research has been done recently in

Canada concerning the sources of productivity change at the firm level.

The intent of this paper is to explore the sources of productivity growth in Ontario Hydro, one of the largest producers of electricity in North America. The growing importance of electric utilities in the Canadian economy is reflected in the fact that the share of real domestic product attributable to this sector has increased from 2.1 per cent in 1971 to 2.6 per cent in 1979, with Ontario Hydro accounting for approximately one-third of the sector's total output. Any slowdown of productivity growth in the electric power sector may have a considerable impact on the rest of the economy because electricity is used as an intermediate input by virtually all other industries, and is widely regarded as one of the most viable domestically produced substitutes for imported OPEC oil.

The ensuing empirical analysis of the production structure of Ontario Hydro provides us with information on the degree of substitution between factor inputs, and the contribution to total factor productivity growth of economies of scale, capacity utilization, and technical change. Furthermore, with respect to scale economies, it enables us to address an important issue raised by Chenery (1952), namely, that if there are increasing returns to scale and growing aggregate demand, this might induce firms to add more capacity

than they might expect to use currently. Such a situation provides a legitimate rationale for Ontario Hydro to "over-capitalize" quite distinct from the one advanced by Averch and Johnson (1962) for a regulated firm. Our analysis also indicates the extent to which technological change affects the optimal mix of inputs, that is, the input bias of technical progress.

2. THE PRODUCTION STRUCTURE AND PRODUCTIVITY OF ONTARIO HYDRO

With an operational area covering about 250,000 square miles, capital assets exceeding $15 billion and electric power sales amounting to 100 billion kilowatt-hours (kwh) in 1980, Ontario Hydro is one of the largest regulated corporations in North America. It is primarily concerned with the provision of electric power to municipalities but also supplies power directly to industrial customers and retail customers, either in rural areas or in communities not served by municipal electric utilities.

Established in 1906 by the Provincial Legislature, the Corporation's mandate or objective is "to meet the requirements of the Ontario community for electric service, including the manner of its provision, so as to result in the greatest overall benefit to that community and in the lowest cost to the customer for that service over the long term." The Power Corporation Act by which Ontario Hydro is governed

stipulates that electric power be provided at cost,[1] which means that the Corporation is financially self-sustaining, deriving no revenue whatsoever from taxes. Consequently, Ontario Hydro is not, strictly speaking, subject to rate of return regulation.

For the period under study, 1956-80, one might usefully distinguish between two major technological eras which characterize Ontario Hydro's operations: the period up to 1966 when hydroelectric installations were the dominant source of electricity, and the period 1967-80 when thermal (fossil plus nuclear) powered installations were the dominant source of electricity. The latter era is further divided into two sub-periods, 1967-73 and 1974-80, in order to determine whether productivity growth has undergone a decline similar to that which has occurred elsewhere in the economy. The actual behaviour of Ontario Hydro's output, the quantities and prices of inputs employed, and productivity performance[2] during these three periods is summarized in Table 1. Three important features warrant attention.

First, there appears to be considerable substitution between factors of production in response to relative changes in their prices, indicating strong own-price as well as cross-price elasticities of substitution, and also in response to the scale of operations. For example, during the periods 1957-66 and 1967-73, fuel and material prices declined relative to those of capital and labour while growth in the use of capital and labour lagged behind that of fuel and

materials. By contrast, during the period 1974-80, fuel and material prices increased relative to those of capital and labour while the use of fuel and materials grew more slowly than that of capital and labour.

Second, although until recently most discussions of productivity focused on labour productivity, which is hardly surprising given the vital role that it plays in improving workers' living standards, it is not the best way to measure gains in efficiency. Indeed, it can be extremely misleading. Labour productivity depends on the quantity (and quality) of other inputs, such as capital, fuel, and materials, that labour has to work with, as well as the efficiency with which all inputs are used in the production process; that is, total factor productivity. It is the latter which is the best single measure of economic efficiency because, unlike labour productivity, it is unaffected by interfactor substitution, induced by changes in relative input prices. Moreover, as shown in Table 1, these two productivity measures can differ widely. Whereas labour productivity growth declined dramatically from an average annual rate of increase of 6.86 per cent during the period 1957-66 to an average annual rate of growth of only 0.20 per cent for the period 1974-80, total factor productivity (TFP) growth rose from -0.13 per cent to 1.11 per cent between the same two periods.

Finally, it should be remarked that the post-1973 slowdown in TFP growth has been far less severe for Ontario Hydro than for most other sectors of the economy.

In order to understand the importance of TFP in accounting for the growth of output, we can make use of the following well-known accounting relationship[3]

$$\dot{Q} = S_K\dot{K} + S_L\dot{L} + S_F\dot{F} + S_M\dot{M} + \dot{TFP} \qquad (1)$$

which states that the rate of growth of output (Q) is the cost-share-weighted sum of the rates of growth of capital (K), labour (L), fuel (F), and intermediate materials (M), plus TFP growth. S_i denotes the cost share associated with input i. The five terms on the right-hand side of equation (1), converted to percentages, are displayed in subsequent rows of Table 2.

Whereas fuel made the greatest contribution to output growth between 1956 and 1966, capital made the greatest contribution during the periods 1967-73 and 1974-80. And while TFP growth had a slightly deleterious effect on output growth from 1956 to 1966, it accounted for 17.9 per cent and 21.9 per cent of output growth respectively during the periods 1967-73 and 1974-80.

Total factor productivity is itself a broad measure of economic efficiency, reflecting a diversity of factors including, managerial efficiency, human capital, economies of scale, research and development, market structure, etc.[4] The rest of this paper is, however, much more limited in scope, being concerned with the decomposition of total factor productivity growth into separate components that may be associated with capacity utilization, scale economies, and technical change. This involves an econometric analysis of Ontario Hydro's production structure.

3. METHODOLOGY

A fundamental result of duality theory is that under certain rather weak regularity conditions, a unique correspondence exists between production and cost functions (Shephard, 1970). The specification of a production function implies a particular cost function, and vice versa. Consequently, the structure of production of a firm can be examined empirically using either a production function or a cost function.

As we noted earlier, Ontario Hydro is required by its mandate to meet the requirements of the Ontario community for electricity at the lowest feasible cost. Managerial decisions are therefore concerned primarily with the determination of the optimal input levels. Hence, it seems reasonable to assume that input levels are endogenous variables and that the

output level is an exogenous variable. Moreover, as Ontario Hydro must compete with other industries for its inputs, input prices can also be regarded as exogenous variables. It follows that estimation of the cost function is more appropriate in the case of Ontario Hydro because it expresses minimal total cost as a function of output and factor prices. A similar approach was adopted by Nerlove (1963), Christensen and Greene (1976), Stevenson (1980), and Gollop and Roberts (1981) in their studies of the U.S. electric power industry.

Assuming that the firm minimizes total cost of production (C), its cost function takes the general form:

$$C = f(P,Q,U,T), \tag{2}$$

where P is a vector of input prices (P_K, P_L, P_F, P_M), Q is the level of output, U denotes the level of capacity utilization, and T is time.

A variant of the translog specification developed by Christensen, Jorgenson and Lau (1971, 1973) is used to represent the minimal cost function:[5]

$$\begin{aligned} lnC = {} & \alpha_0 + \sum_i \alpha_i lnP_i + \alpha_Q lnQ + \alpha_T T \\ & + \sum_i \sum_j \alpha_{ij} lnP_i lnP_j + \sum_i \alpha_{iU} lnP_i lnU \\ & + \sum_i \alpha_{iT} lnP_i T + \alpha_{QU} lnQ lnU. \end{aligned} \tag{3}$$

Without loss of generality we place some parametric restrictions on the translog function (3) to ensure symmetry and to satisfy the theoretical requirement of linear homogeneity in input prices. However, no prior restrictions are imposed with respect to the substitution possibilities among factors of production, the extent of economies of scale, the degree of homotheticity, or the particular form of technical change.

By partially differentiating (3) and using Shephard's lemma, a set of cost-share equations are obtained:

$$S_i = \alpha_i + \sum_j \alpha_{ij} \ln P_j + \alpha_{iU} \ln U + \alpha_{iT} T. \qquad (4)$$

We can then compute the Allen-Uzawa partial elasticities of substitution between two inputs i and j, σ_{ij}, as well as the output-compensated own- and cross-price elasticities of demand, ε_{ii} and ε_{ij} (Binswanger, 1974)

$$\sigma_{ij} = (\alpha_{ij}/S_i S_j) + 1 \qquad \text{for } i \neq j, \qquad (5)$$

$$\sigma_{ii} = (\alpha_{ii} + S_i^2 - S_i)/S_i^2 \qquad \text{for all } i, \qquad (6)$$

$$\varepsilon_{ii} = (\alpha_{ii}/S_i) + S_i - 1 \qquad \text{for all } i, \qquad (7)$$

$$\varepsilon_{ij} = (\alpha_{ij}/S_i) + S_j \qquad \text{for } i \neq j. \qquad (8)$$

The elasticity of cost with respect to output ε_{CQ} can be interpreted as a measure of scale economies. If ε_{CQ} is less (greater) than unity, cost increases less (more) than proportionately with increases in output, implying the existence of scale economies (diseconomies). If ε_{CQ} equals unity, we have constant returns to scale. From the translog function (3)

$$\varepsilon_{CQ} = \alpha_Q + \alpha_{QU} \ln U, \tag{9}$$

which will vary with the level of capacity utilization.

Similarly, the impact of changes in capacity utilization is captured by ε_{CU}, the elasticity of cost with respect to capacity utilization. From the translog function,

$$\varepsilon_{CU} = \sum_i \alpha_{iU} \ln P_i + \alpha_{QU} \ln Q. \tag{10}$$

Finally, the translog cost function (3) also allows for neutral as well as biased technical change. The rate of technical change ($\dot{A}$) may be represented as a time-related shift in the cost function so that

$$\dot{A} \equiv - \frac{\partial \ln C}{\partial T} = -(\alpha_T + \sum_i \alpha_{iT} \ln P_i). \tag{11}$$

Neutral technical change acts as a pure shift in the cost function leaving input shares unchanged, and is represented by the parameter α_T. Biased technical change represents shifts in the level of technology that alter equilibrium input shares, holding input prices constant, and is described by the parameters α_{iT}. Technical change is said to be ith-input using (i-saving) if the ith input's cost share is increased (reduced) and is represented by $\alpha_{iT}>0(\alpha_{iT}<0)$. It follows that if technical change is ith-input using (saving), an increase (decrease) in P_i will reduce (increase) technical change.

In order to estimate the parameters of the translog cost function, we follow Christensen and Greene (1976) and estimate jointly the cost function and the cost share equations as a multivariate regression system, a procedure which greatly increases the statistical degrees of freedom. Two steps are involved. Having specified additive disturbances for each of the share equations (4) and for the cost function (3), we first estimate the coefficients of the share equations, subject to symmetry and homogeneity restrictions discussed earlier,[6] using an iterative Zellner estimation procedure. Then, given the estimates of the parameters of the cost share equations, the second step involves the estimation of the remaining parameters of the cost function (3).[7]

4. EMPIRICAL RESULTS

Parameter estimates for the model of production outlined in the previous section are reported in Table 3. These estimates are then used to compute estimates of the own- and cross-price elasticities shown in Table 4. They are also used to determine the contributions of scale economies, changes in capacity utilization, and technical progress, to the post-1973 slowdown in estimated total factor productivity growth.

As one would expect, the own-price elasticities are negative, with capital and labour price-elastic, and fuel and intermediate materials price-inelastic. The cross-price elasticities between capital and the other three inputs are positive, implying that they are substitutes for capital. Labour and fuel are fairly strong substitutes, whereas intermediate materials are rather weak substitutes for capital. By contrast, negative cross-price elasticities indicate that labour, fuel, and intermediate materials are complements to each other.

The degree of scale economies is measured by the elasticity of cost with respect to output, ε_{CQ}. Our results show that between the two periods 1967-73 and 1974-80, the estimate of ε_{CQ} changed very little, averaging 0.63 in the former period and 0.65 in the latter period. Hence, on average, a 1 per cent increase in output leads to

approximately a 0.64 per cent increase in costs which suggests substantial economies of scale for Ontario Hydro's operations. This result appears to conflict with Christensen and Greene (1976) who found evidence of only minimal scale economies for the larger firms in their sample. However, their study only focused on electric power generation, whereas our research deals with a utility involved not only in the generation but also the transmission and distribution of electricity. As pointed out by Gollop and Roberts (1981), although economies in generation may be exhausted at a relatively small scale of operation, engineering considerations suggest that significant economies may still exist in both transmission and distribution.[8] Our findings are not, however, inconsistent with those of Gollop and Roberts (1981), who arrived at estimates of ε_{CQ} that vary between 0.68 and 0.90.[9]

Capacity utilization also has an important bearing on costs and, consequently, TFP growth. According to our model, ε_{CQ} is a function of U given by Equation (9). As α_{QU} was found to be negative, we can conclude that an increase in U leads to greater scale economies, and therefore has an indirect effect on costs. It also has a direct effect on costs through ε_{CU}, which, according to equation (10), itself depends on input prices and output. Not surprisingly,

our estimates indicate that ε_{CU} is negative. Moreover, it changed very little, averaging -0.43 during the period 1967-73 and -0.42 during the period 1974-80. As $\alpha_{LU}<0$ and $\alpha_{KU}, \alpha_{FU}, \alpha_{MU}>0$, we may infer that increases in capacity utilization are labour-saving and capital-, energy-, and material-using. This means that when capacity utilization is increasing, the productivity of labour rises while that of capital, fuel, and materials decreases.

TFP growth is not only affected by scale economies and capacity utilization, but also by technical change. The rate of technical change $\dot{A}$, as defined in equation (11), is itself affected by changes in input prices. The parameter estimates reported in Table 3 suggest that technical change is capital-, labour-, and material-saving but fuel-using, findings that are consistent with those of Stevenson (1980) as well as those of Gollop and Roberts (1981).[10] The fact that technical change is fuel-using ($\alpha_{FT}>0$) means that increasing fuel prices not only encourage substitution of other inputs for fuel, but also make the adoption of fuel-using innovation more expensive. This results in a lower rate of cost reduction associated with technical change. By contrast, as technical change is capital-, labour-, and material-saving, increases in the prices of these inputs tend to encourage technical progress.

Given our estimates of ε_{CQ}, ε_{CU} and $\dot{A}$, we can determine the sources of TFP growth for Ontario Hydro, as well as the reasons for its slowdown. Following Denny, Fuss and Waverman (1981) and Nadiri and Schankerman (1981), estimated total factor productivity growth $\dot{TFP}^*$ can be decomposed into parts related to scale economies, capacity utilization and technical change,

$$\dot{TFP}^* = (1 - \varepsilon_{CQ})\dot{Q} - \varepsilon_{CU}\dot{U} + \dot{A} \ . \qquad (12)$$

Estimated TFP growth during the period 1967-73 averaged 2.11 per cent annually, with scale economies, changes in capacity utilization, and technical progress respectively, contributing 144.1 per cent, -72.5 per cent and 28.4 per cent. $\dot{TFP}^*$ dropped to an average annual rate of 1.25 per cent for 1974-80 when the respective contribution of scale economies, changes in capacity utilization, and technical progress were 140.8 per cent, -59.2 per cent and 18.4 per cent.

It follows that the 0.86 percentage point drop in TFP growth was primarily due to the slowdown in output growth, which fell from an average annual growth rate of 8.08 per cent for 1967-73 to 5.07 per cent for 1974-80 and thereby resulted in a loss of scale economies. This decline in output growth would itself have reduced TFP growth by 1.28 percentage points to 0.83 per cent instead of to the estimated 1.25 per cent for the period 1974-80. Measured technical progress also declined

between the two periods, largely as a result of increasing fuel prices, contributing a further 0.37 percentage points to the decline. Thus, if other things had remained constant, TFP growth would have dropped to a mere 0.46 per cent in 1974-80.

Fortunately, however, other things did not remain constant. Although capacity utilization declined throughout both periods 1967-73 and 1974-80, it did so rather more slowly in the latter period, thereby making a positive contribution to TFP growth of 0.79 percentage points.[11]

5. CONCLUSIONS AND POLICY IMPLICATIONS

As we have remarked in section 1, Ontario Hydro's recent productivity performance compares quite favourably with that of the rest of the economy, at least as far as the period subsequent to 1967 is concerned. Whereas TFP growth in the economy as a whole declined from an average annual rate of 2.23 per cent during the period 1967-73 to -0.03 per cent for the period 1974-80, TFP growth at Ontario Hydro fell from 1.45 per cent to 1.11 per cent between the same two periods. As a result, from 1967 to 1980, TFP growth averaged 1.28 per cent annually at Ontario Hydro as opposed to 1.16 per cent for the economy as a whole.

The empirical results presented in section 4 suggest that the slowdown in productivity growth that took place at Ontario

Hydro between the periods 1967-73 and 1974-80 may be attributable to two main developments, both of which were largely beyond the Corporation's control. First and foremost, there was a marked decline in the growth of demand for electric power occurring as a consequence of the general slowdown in aggregate demand, and which was compounded in the case of Ontario Hydro and other electric utilities by measures designed to encourage energy conservation in the wake of the OPEC oil price increases. Second, technical progress slowed down mainly because of increasing fuel prices.

Our findings also cast considerable doubt on the hypothesis advanced by Baily (1981) that the sharp increases in fuel prices after 1973 have resulted in the premature obsolescene of capital which, in turn, has led to a drop in capacity utilization and thus contributed to a decline in measured TFP. This suggests a high degree of complementarity between fuel and measured capital stock. Sharp increases in fuel prices would be expected to have a particularly large effect on Ontario Hydro's operations because they are extremely capital-intensive, and fuel constitutes a major input. However, not only were capital and fuel found to be substitutes for each other in the corporation's production process, but, as pointed out earlier, TFP growth declined much less at Ontario Hydro than in the economy as a whole. Moreover, although capacity utilization has fallen since 1973,

it has done so at a much slower rate than during the 1967-73 period.

At the same time, our analysis suggests a number of steps that would improve Ontario Hydro's productivity performance. In this regard, both the Federal and Ontario Governments, as well as Ontario Hydro itself, each have a role to play.

As far as the two levels of government are concerned, any stimulus to aggregate demand would likely increase the demand for electricity and thus improve Ontario Hydro's productivity performance through scale economies (and greater use of capacity). The existence of substantial scale economies also suggests that there is a significant trade-off between the benefits of electricity conservation and TFP growth. It follows that if scale economies in the production of electric power are greater than in other energy producing sectors such as oil or gas, energy conservation measures should place more emphasis on encouraging the substitution of electricity for other energy sources. One might even consider further taxing the use of oil and gas and perhaps subsidizing the use of electricity.[12]

Ontario Hydro also has an important role to play in improving its own productivity performance. Whereas in the past, the presence of considerable economies of scale (1.54) and a growing demand for electricity may have justified

capital expenditures in excess of current requirements and thus resulted in reduced capacity utilization, future productivity performance can be improved substantially by greater utilization of existing capacity. Consequently, Ontario Hydro should adopt a more aggressive marketing strategy in order to increase its sales relative to those of its competitors from the oil and gas industries, not just in Ontario, but also in export markets. Surprisingly enough, unlike most other firms of similar size, Ontario Hydro does not even have a marketing department.

Furthermore, rather than promote the conservation of electricity in general, consideration should instead be given to the possibility of introducing "peak load" or "time of day" pricing structures in order to encourage less variable usage patterns by customers and thereby increase the proportion of base load to peak load plant. Such a step could improve productivity in two ways. First, it would flatten the load pattern and reduce the need for additional plant to satisfy increasing peak demands for electricity. This would tend to increase the level of capacity utilization and, as a result, productivity. Second, as peak load plant generally uses more fuel than does base load plant,[13] and technical progress is fuel-using but capital- (labour- and material-) saving, it follows that time of day or peak load pricing would mitigate the adverse impact on technical progress of increasing fuel prices.

Finally, the importance of electric power as an intermediate input for other sectors of the economy implies that improvements in Ontario Hydro's productivity performance could have a salutary effect on TFP growth elsewhere. Evidence by Rao and Preston (1983) suggests that in most manufacturing industries technical progress is energy-using. Consequently, in so far as improvements in Ontario Hydro's productivity growth are reflected in a slower rate of increase in electricity prices, this will in turn facilitate technical progress and therefore improve TFP growth in the manufacturing sector.

Table 1

Average Annual Percentage Rates of Growth of Output, Inputs, Input Prices, and Productivity, 1957-80

		1957-66	1967-73	1974-80
Output		6.09	8.08	5.07
Inputs:	capital	4.49	4.80	5.59
	labour	-0.77	5.67	4.90
	fuel	29.70	12.90	3.51
	materials	8.10	7.10	-3.46
Input prices:	capital	2.15	7.65	10.86
	labour	3.36	10.03	9.57
	fuel	1.11	3.04	23.44
	materials	0.36	6.22	14.95
Labour Productivity		6.86	2.40	0.20
Total Factor Productivity		-0.13	1.45	1.11

Table 2

Sources of Output Growth, 1957-80

	1957-66	1967-73	1974-80
		(%)	
Capital ($S_K\dot{K}$)	40.4	27.2	50.6
Labour ($S_L\dot{L}$)	- 3.4	16.1	20.2
Fuel ($S_F\dot{F}$)	47.0	25.2	15.1
Materials ($S_M\dot{M}$)	18.2	13.6	- 7.8
$\dot{TFP}$	- 2.2	17.9	21.9

Table 3

Translog Cost Function Parameters

Parameter	Estimate	Parameter	Estimate
α_Q	0.7757 (4.08)	α_{FM}	-0.0688 (5.11)
α_T	-0.0053 (0.43)	α_{MM}	0.0070 (0.32)
α_{QU}	-0.0525 (5.59)	α_{KU}	0.1502 (0.82)
α_{KK}	-1.1464 (3.49)	α_{LU}	-0.3056 (3.79)
α_{KL}	0.8086 (2.56)	α_{FU}	0.1125 (1.18)
α_{KF}	0.2184 (3.38)	α_{MU}	0.0430 (1.04)
α_{KM}	0.1194 (1.90)	α_{KT}	-0.0019 (2.03)
α_{LL}	-0.6052 (3.30)	α_{LT}	-0.0068 (4.63)
α_{LF}	-0.1458 (4.26)	α_{FT}	0.0102 (5.99)
α_{LM}	-0.0577 (1.44)	α_{MT}	-0.0015 (1.97)
α_{FF}	-0.0039 (0.13)		
$R^2 = 0.9869$	MSE = 0.00116	D.W. = 1.84	

Note: t-statistics in parentheses.

The constant terms α_0, α_K, α_L, α_F and α_M are not reported on the grounds that they do not play any explanatory role in our analysis.

Table 4

Estimated Own- and Cross-Price Elasticities

Elasticity	Estimates	
	1967-73	1974-80
ε_{KK}	-3.0436	-3.0572
ε_{LL}	-3.4223	-3.7106
ε_{FF}	-0.8667	-0.8002
ε_{MM}	-0.7998	-0.8222
ε_{LK}	4.0041*	4.3580*
ε_{KF}	1.8489	1.4637
ε_{KM}	-0.4154	-0.3766
ε_{LF}	-0.4808	-0.4859
ε_{LM}	-0.0980	-0.1636
ε_{FM}	-0.2829	-0.2019

Note: All variables significant at 99% confidence interval.
*significant at 90% confidence interval.

APPENDIX

Data Base

The raw data used to compute both the output and inputs (capital, labour, fuel, and intermediate materials) in current and constant prices (1980$) were provided by Ontario Hydro. A detailed description of the data can be found in Drapkin (1978).

Aggregate output is measured by the sum of revenues for four service classes (municipal, retail, direct, and secondary), with each class deflated using a class-specific, chain-linked Laspeyres price index.

The stock of capital is defined as the sum of tangible plant, cash, net accounts receivable, and inventories of fuel and materials. The price of capital services is the sum of an expected real rate of interest of 6 per cent plus the depreciation rate, all multiplied by the Ontario Hydro Composite Plant Index. Note that the depreciation rate takes into account changes in the composition of capital stock.

The labour input is measured by man-hours available for work and thus excludes time lost due to sickness, absence, vacations, holidays, and periodic reductions in the contract

work week, as well as the portion of productive hours charged to capital accounts, which is already included in the cost of plant. (Quality adjustment of measured labour input to account for changes in the occupational-seniority mix was not possible, due to insufficient data.) An implicit price index for labour services was obtained by dividing total employee expenses by total man-hours worked.

The fuel input is a composite of six types of fuel -- coal, oil, natural gas, processed uranium, and ignition fuel, plus water. The quantity bases used for coal, oil, natural gas, and ignition fuel are all expressed in gigajoules of equivalent heat rate, while for uranium megagrams are used. A composite index of fuel expense is computed as the ratio in each year of current to constant dollar total fuel expense.

Intermediate materials consist of purchased power and other expenses. To arrive at an input measure, purchased power expenses are deflated by an index of prices per kilowatt-hour paid by Ontario Hydro to power suppliers, and other expenses were deflated by the GNE index.

Finally, capacity utilization is defined as primary peak demand (kw) divided by dependable peak capacity (kw).

Footnotes

1 The Act defines cost as including charges for operation, maintenance, administration, and power purchased, together with fixed charges which include interest, depreciation, and provisions for the retirement of debt over a 40-year period.

2 Interestingly enough, Ontario Hydro is one of the few corporations in Canada which measures total factor productivity growth on an ongoing basis for planning purposes (Drapkin, 1978).

3 See, for example, Berndt and Watkins (1981).

4 See, for example, Denison (1962, 1967) and Star (1974).

5 Due to insufficient degrees of freedom, we were unable to follow the general rule of allowing variables to interact with each other and with all the first- and second-order translog terms. The interaction terms that have been left out were excluded on the basis of hypothesis tests.

6 In addition to these restrictions, other conditions had to be met. For the cost function to be well behaved for all input price combinations, increases in each input price must lead to an increase in total cost. Therefore, the predicted cost shares must be non-negative at each data point. This condition is called either monotonicity or positivity. Moreover, if the cost function is to be well behaved, it must be concave in input prices, which requires that the Hessian matrix be negative semi-definite.

7 It is, of course, preferable to estimate the share and cost functions simultaneously. Unfortunately, with the software available to us, this method is considerably more complex than the two-step procedure we have used, and the pay-off from adopting such an estimation procedure is unlikely to be sufficient to warrant the additional costs involved. In any event, two-step estimators are consistent (Dhrymes, 1971).

8 Christensen and Greene (1976), as well as Gollop and Roberts (1981), also concerned themselves with utilities where electricity was mainly generated by fossil fuel powered installations. At Ontario Hydro such installations account for only about 35 per cent of total generation plant.

9 A better way of estimating the degree of scale economies would be to use cross-section data on a sample of small and large firms that have adopted similar technologies and operate in similar market and regulatory environments. Unfortunately, in Canada electric utilities are so small in number and diverse in character that a sufficiently large sample cannot be obtained, and the technology mix used by Ontario Hydro is quite different to that employed by other Canadian electric utilities.

10 In models involving only three inputs, Stevenson (1980) finds that technical change in electric utilities has been capital- and labour-saving and fuel-using, while Gollop and Roberts (1981) conclude that technical change is capital-neutral, labour-saving, and fuel-using.

11 The depletion of resource rents may also have a bearing on Ontario Hydro's productivity performance. Greater rents are associated with the generation of electricity from hydraulic than from fossil fuel or nuclear powered plants. The exhaustion of Ontario's endowment of large hydraulic sites has meant that increasing demands for electricity could only be met by constructing more technologically diverse fossil fuel and nuclear powered plants that are more costly to operate in terms of material and fuel consumption. Unfortunately, direct estimation of hydro resource rents for each year is a hazardous exercise, far beyond the scope of this study (see Zuker and Jenkins (1983) for estimates for 1979). Nevertheless, an attempt was made to capture the possible effect of changes in resource rents indirectly by including in the transloq function a capital mix variable X denoting hydraulic plant as a proportion of total generating capacity. The coefficient of lnX was positive, thus suggesting that the changing mix did in fact have an adverse, albeit minor, effect on TFP growth. However, the mix of capital stock is already reflected in the price of capital, so that it is not really appropriate to include a separate mix variable in the translog cost function.

12 According to Zuker and Jenkins (1983), the actual cost of resources employed by electric utilities is already less than the opportunity cost. Further subsidization of electric power may therefore not be an acceptable method of encouraging the substitution of electricity for other types of energy. It should also be pointed out that any departure from marginal cost pricing would not affect our estimates of TFP growth for Ontario Hydro provided the price of electricity remained a constant proportion of marginal cost throughout the period under examination.

13 Base load plant is mainly of the hydraulic- and nuclear-powered type with much of the peak load requirements being met by fossil-fuel-powered plant.

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